

Lidar and Surface Observations of a Cold Frontal Case: The 15 April 1994 ARM RCS IOP Case

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1. INTRODUCTION

A cold frontal passage was observed on the night of April 14-15, 1994 during the Atmospheric Radiation Measurement (ARM) Remote Cloud Sensing (RCS) Intensive Operational Period (IOP) at the Southern Great Plains (SGP) Cloud And Radiation Testbed (CART) site near Lamont, Oklahoma. A number of sensors, including the Goddard Space Flight Center Scanning Raman Lidar (SRL) were operational. The SRL (Ferrare et al., 1995) was operated in alternating vertical and near-horizontal pointing modes, each with 1-minute dwell time, yielding a high (75 m) resolution, nighttime profile of water vapor mixing ratio data to altitudes of 8 km.

There is extensive literature concerning cold fronts, undular bores and drylines, e.g., Christie et al.(1978), Simpson (1987), Crook (1988) and references therein. However, the SRL observations presented here are unique in that a detailed description of the interaction between a dryline, bore and cold front was obtained using highly resolved water vapor mixing ratio ($g\ kg^{-1}$) data.

The SRL and ancillary data sets collected during the night of April 14-15, 1994, are presented and interpreted below. A wavelet analysis of the SRL data and the surface pressure record is also presented.

2. SYNOPTIC CONDITIONS

Surface and satellite charts at 2200 (all times are UTC) 14 April 1994 showed a low pressure system centered over Colorado and moving south-southeast into northern Texas and Oklahoma, while much of Oklahoma and Texas were under the influence of a

poleward moving airmass of high moisture content (Fig. 1). By late afternoon on 14 April, the confluence of these systems led to a line of severe thunderstorms through the central United States.

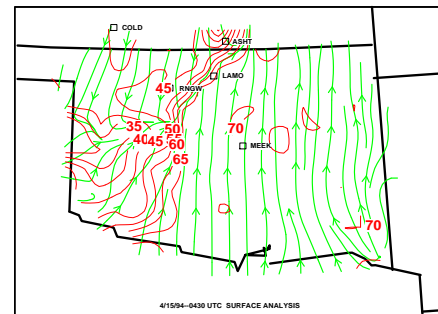


Figure 1. Streamline and dew point temperature ($^{\circ}F$) analysis of surface observations from the Oklahoma Mesonet, NWS, and ARM stations on 15 April, 1994.

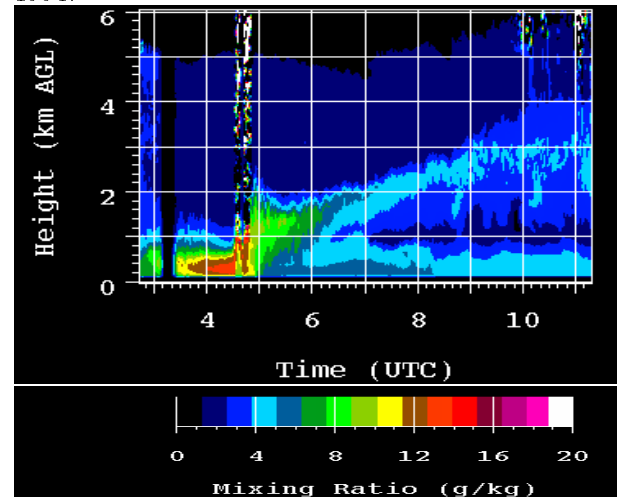


Figure 2. SRL mixing ratio ($g\ kg^{-1}$) profiles on 15 April 1994 during the ARM RCS IOP showing the undular bore, cold frontal surface and the mid-tropospheric inversion.

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3. SRL DATA

The SRL data (Fig. 2) revealed the dramatic interaction between a nocturnal dryline and a cold front that triggered intense wave activity including an undular bore complete with roll clouds at about 0430. The night started with the formation and northward propagation of a dryline that was oriented from SW to NE through central Oklahoma (at 0300). The dry-moist boundary had an eastward tilt and rose to about 0.7 km before joining a strong inversion dominated by wave activity. This moist boundary layer was capped by a well-mixed layer that extended to about 5.0 km where a further sharp drop in mixing ratio occurred. Such layering combined with the dryline and the cold front was an ideal situation for the development and sustenance of the undular bore at 0430, as well as prior and subsequent wave activity. The SRL measurements also showed a turbulent region that occurred after the passage of the bore (and the surface cold front) and likely indicates a dissipation mechanism for the bore undulations.

4. SURFACE OBSERVATIONS

Surface observations at the CART site are shown in Fig. 3. Embedded in the trend of rising pressure is a series of impulsive pressure jumps similar to those described by Tepper (1950). The largest of these jumps (1.8 mb in less than 2 minutes) occurred at 0430 followed by a series of small amplitude oscillations. This jump, the associated roll clouds and temperature signature are characteristic of an undular bore (Simpson, 1987). Small amplitude pressure jumps (0.3 to 0.4 mb) were also recorded around 0100 and 0330 and were again followed by small scale oscillations.

Surface temperature exhibited a similar variability superposed on an overall cooling trend. A perturbation of about 0.5°C at about 0100 and a series of jumps between 0250 and 0330 (ranging from 1 to 2°C in magnitude) were associated with increased wind speed, a shift in wind direction, and a jump in pressure consistent with weak gravity/bore wave oscillations. The temperature at 0430 rose by more than 3°C due to mixing by the undular bore¹. The proximity of the bore to the front made positioning of the cold front from surface measurements difficult. However, SRL measurements of mixing ratio differences of

pre- and post-bore airmass showed the frontal boundary to be a good half hour behind the bore (0500-0530).

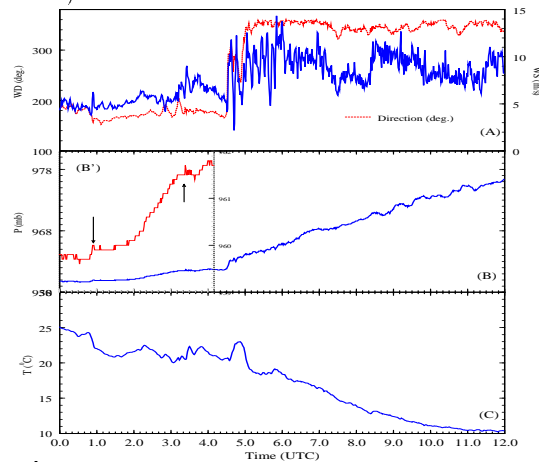


Figure 3. Surface observations of wind, pressure, and temperature near Lamont, OK on 15 April 1994. A magnified plot of the pressure records between 0000 - 0400 is shown in B'.

5. FREQUENCY ANALYSIS

Spectral analysis of the water vapor and ancillary data failed to resolve even the dominant wavelengths apparent in Fig. 2. However, wavelet analysis yielded a more definitive characterization of the wave structure in frequency-time space. The real part of our wavelet analysis of the SRL measured column integrated precipitable water vapor during the undular bore time period is shown in Fig. 4. A plot of the modulus of the wavelet transform of the surface pressure perturbations (derived using a 5^{th} degree polynomial approximation of the frontal signature and trends) is also shown in Fig. 5. The results depict the relative amplitude of local water vapor undulations as a function of time and frequency in octaves². An interesting result deduced from these graphs is that the frequency of the undular bore and most other wave signatures during the night increased (upward shift) steadily. The undular bore period shifted from about 12.5 minutes at 0430 to 6.25 minutes around 0500.

²An octave of zero corresponds to a period of 12.5 minutes and doubles(halves) for unit increase (decrease) in octave. In the pressure plot, octave zero corresponds to a period of 6.25 minutes. The reason for this shift in frequency is the different data collection rates employed by the instruments (i.e., zero octave defined relative to sampling frequency). The pressure data was collected every minute while the SRL data was recorded every 2.25 minutes.

¹Note that the increase in temperature associated with a bore is mainly due to the downward mixing of air above the inversion level.

This may be explained by the fact that the main parameter controlling wave characteristics in such conditions (Lindzen and Tung, 1976; Smith, 1988) is the depth of the lower moist layer, the “duct”, which was continuously decreasing. The pressure transform indicated that the bore undulations were part of a signal that started earlier in the day and was continuously shifting in frequency. This suggests that the undular bore at 0430 was an extension of the weak bore-like signals at 0100 and 0330 mentioned above.

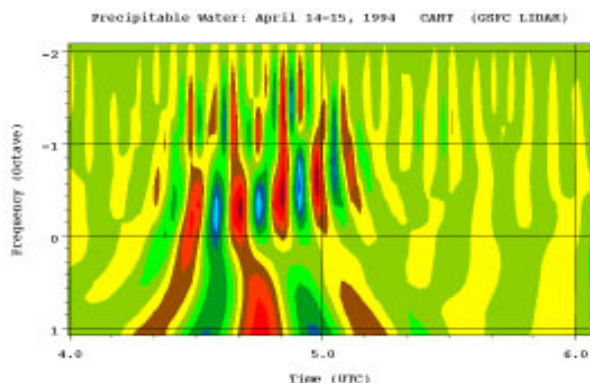


Figure 4. A wavelet analysis of precipitable water (cm) derived from the SRL measured water vapor mixing ratio ($g\ kg^{-1}$) data during the undular bore time period on the night of 15 April 1994.

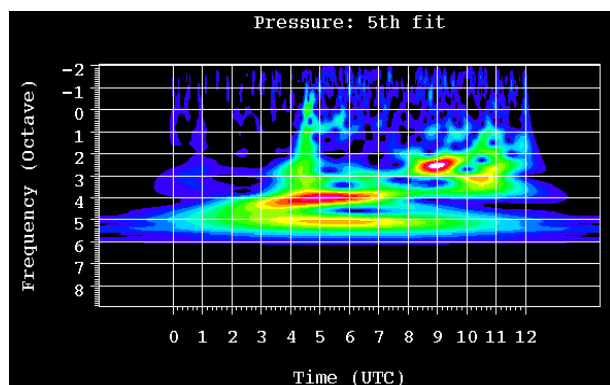


Figure 5. A wavelet analysis of surface pressure (mb) data during the undular bore event on the night of 15 April 1994.

6. SUMMARY

We have presented and discussed a high temporal resolution water vapor profile data set collected during a cold frontal passage in the central United States. The data is unique in that it captures the development and structure of the nighttime boundary layer

associated with a dryline and a cold front, and the interaction of these two meteorological systems. These interactions resulted in an undular bore and preceding wave signatures. Turbulent decay of the bore undulations via mixing was observed during the post frontal period. Wavelet analysis of the data provides highly useful characterization of the full continuum of events in time-frequency space that the standard Fourier methods are unable to resolve. Finally, these observations testify to the usefulness of the SRL as an instrument of great importance in probing the structure and development of meteorological events in the lower troposphere.

7. REFERENCES

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